Neutron Suppression Regions at the Lunar Poles

Part 1:
LEND data quality

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Lunar Science Forum
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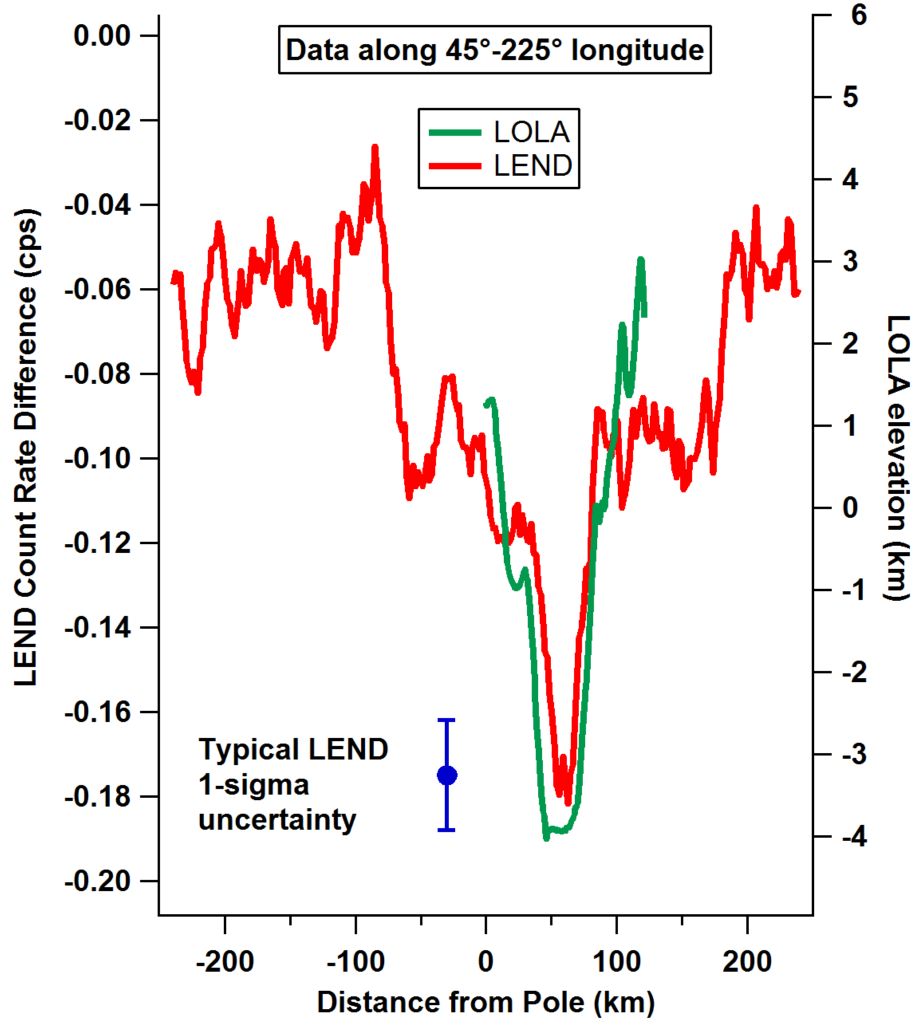
Why this part of presentation?

- Lunar volatiles session at 2012 LPSC
    - Two talks had nothing to do with lunar volatiles
    - They were there to criticize the LEND data quality
    - No time for rebuttal
- Comment to a blog on behindtheblack.com
    - "You neglect to mention yet another possibility — that this paper and its conclusions are seriously flawed in almost every respect." Paul Spudis
- We should be beyond this by now.

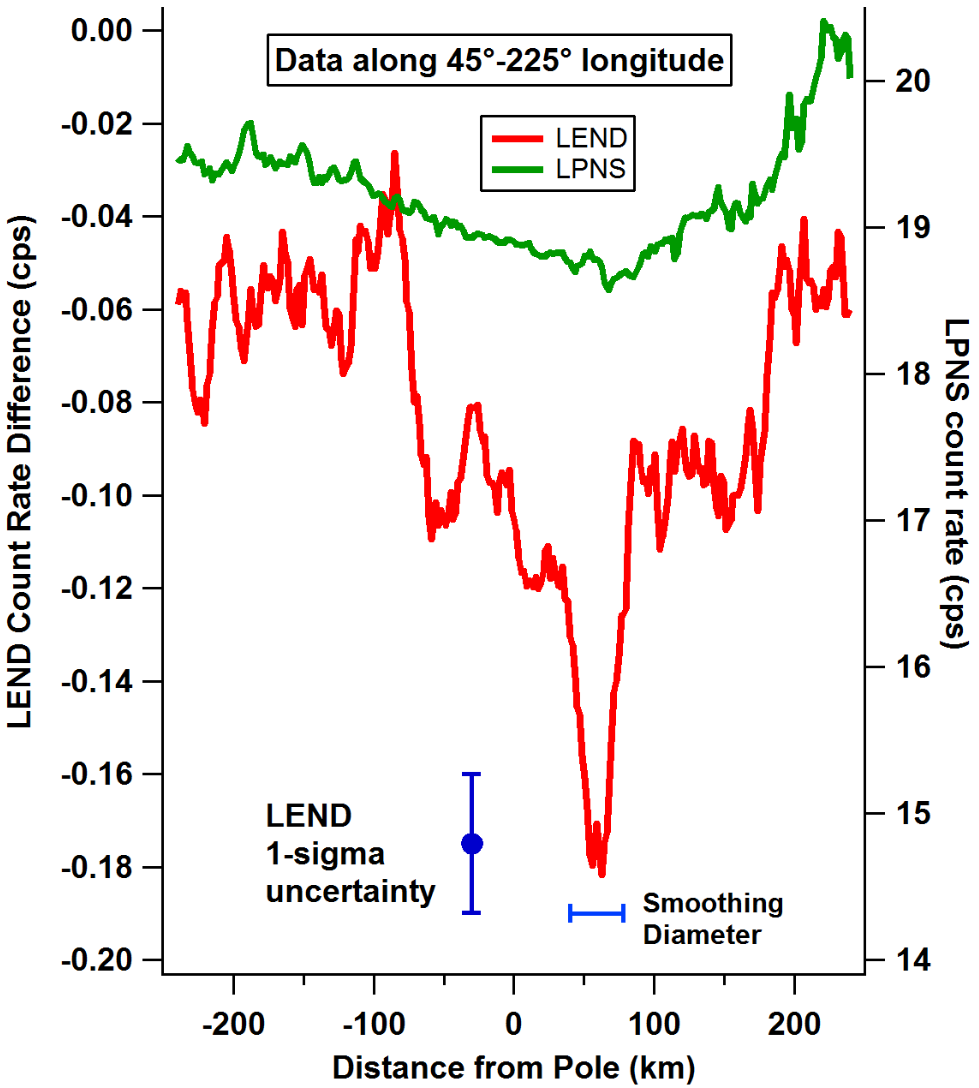
Excellent spatial resolution

- Epithermal neutron flux along 45° - 225° longitude shows a large decrease at Shoemaker Crater.
- Relative to low-H region in low latitudes, decrease is at 12 sigma.
- Relative to terrain 200 km away, it is still at 8 sigma.
- Can't be by chance



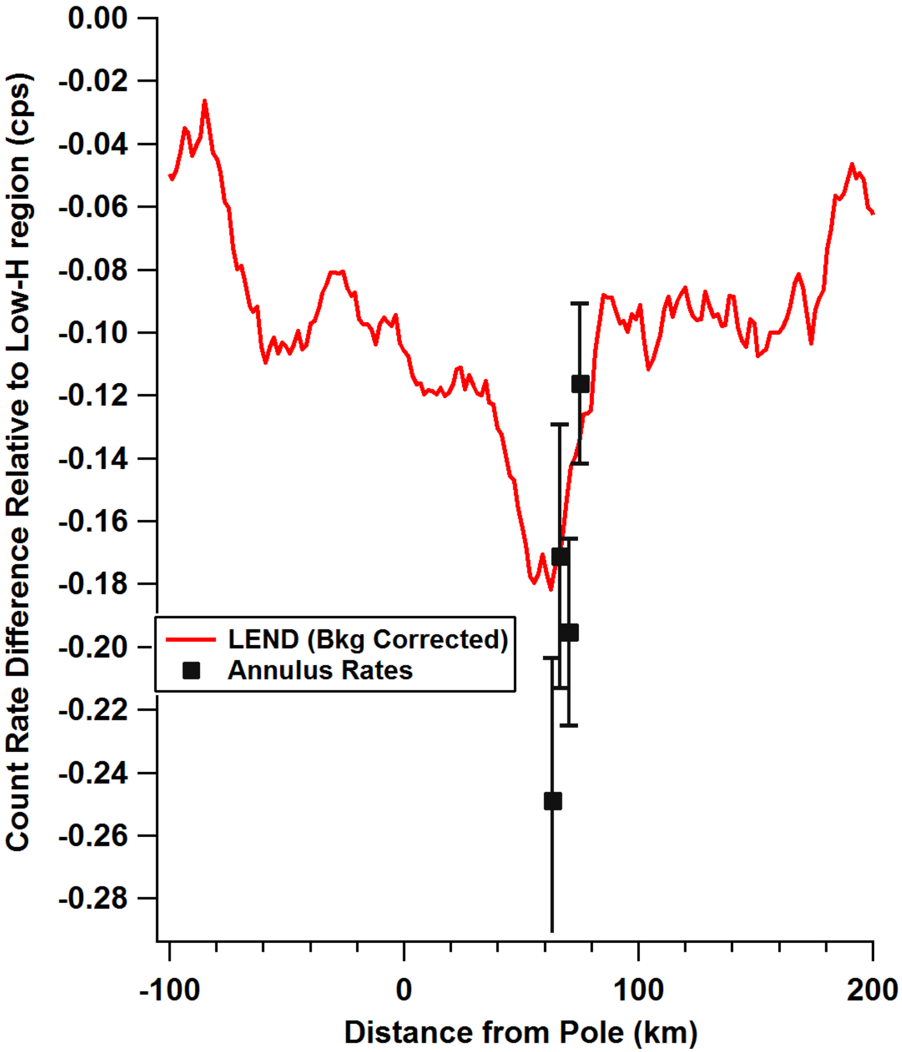
LEND resolution vs LPNS

- Critics have said LEND resolution should not be significantly better than that of LPNS.
- You be the judge.



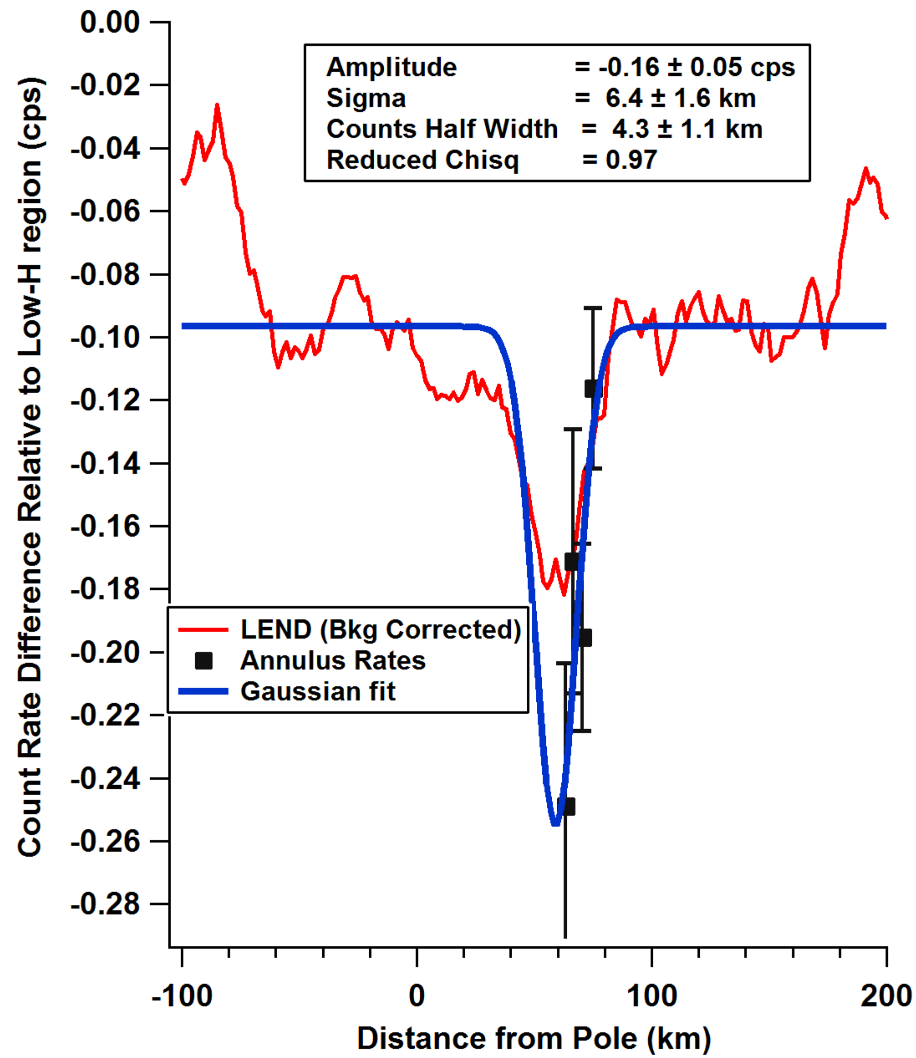
LEND data averaged in rings

- Smoothing improves statistics, but it degrades spatial resolution.
- Unsmoothed data are averaged in four different sized annuli around Shoemaker.
- Data show large uncertainties but also a large suppression.



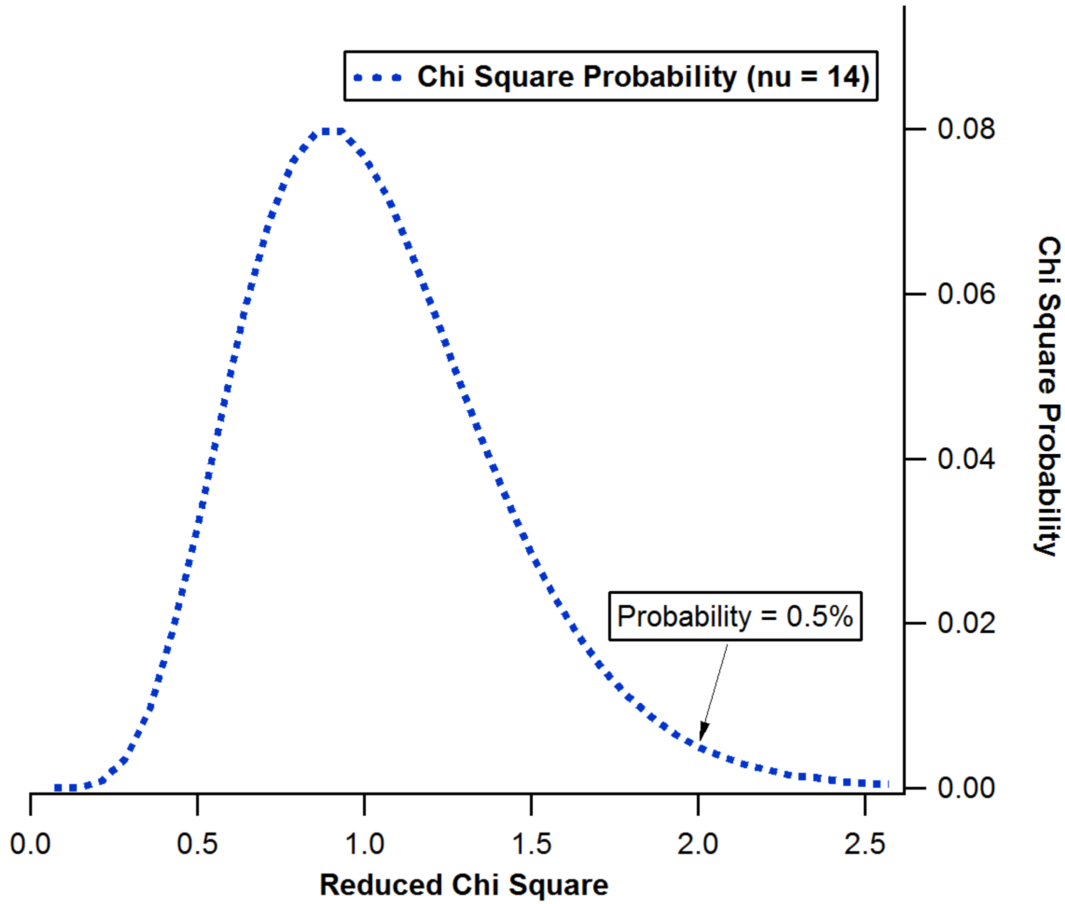
Spatial resolution is as stated

- The data were fit to a Gaussian
- Width of the Gaussian = 6.4 ± 1.7 km
- Equivalent to half width at half counts = 4.3 ± 1.2 km.
- Width cited in Mitrofanov *et al*., 2008 was 5 km.



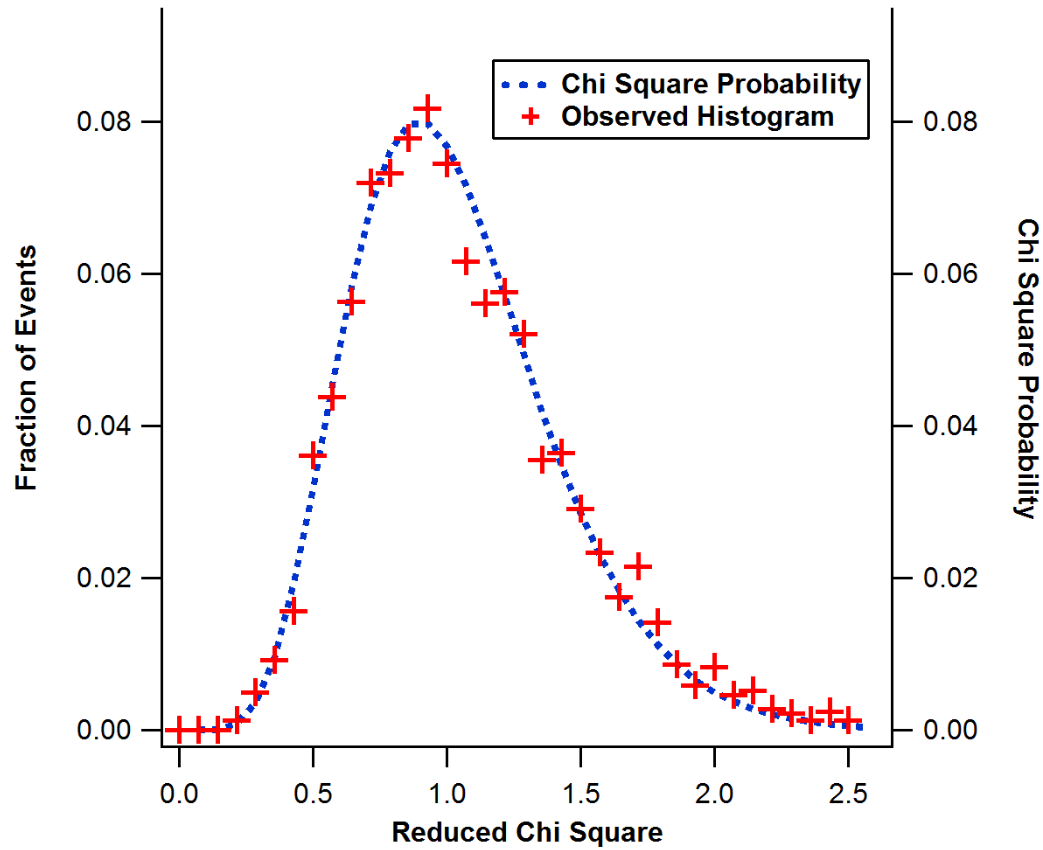
Reduced chi squared test

- Reduced chi squared test is a good test to see if the scatter in the data is consistent with estimated uncertainties.
- If uncertainties are properly estimated, chi squared will be about 1.0
- Graph is 14 degrees of freedom, i.e. averaging 15 points.



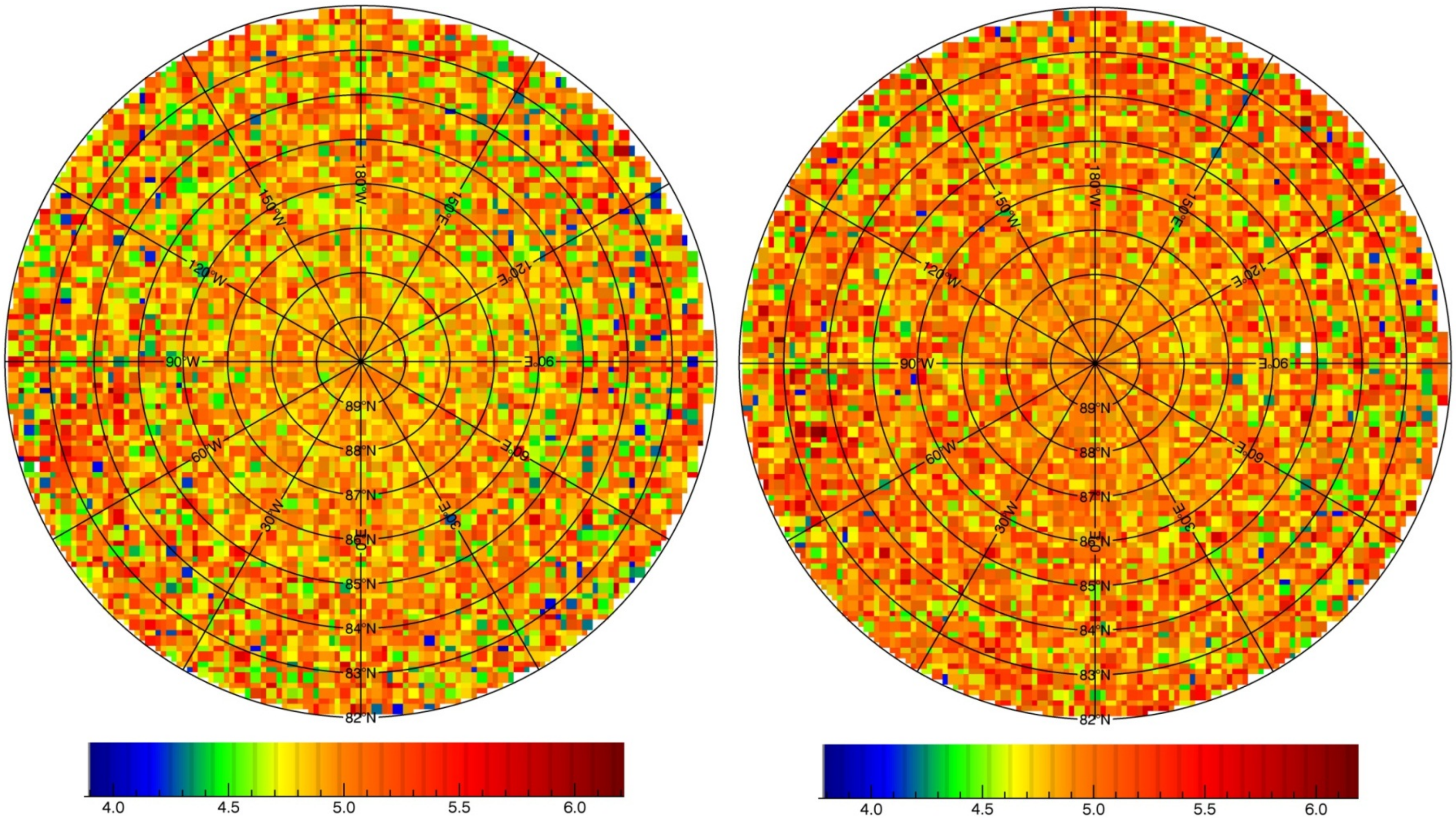
LEND uncertainties are proper

- In making our maps, we need to average 15 values 3263 times.
- Histogram of 3263 different determinations of reduced chi squared show that our uncertainties account for all the scatter in the data.



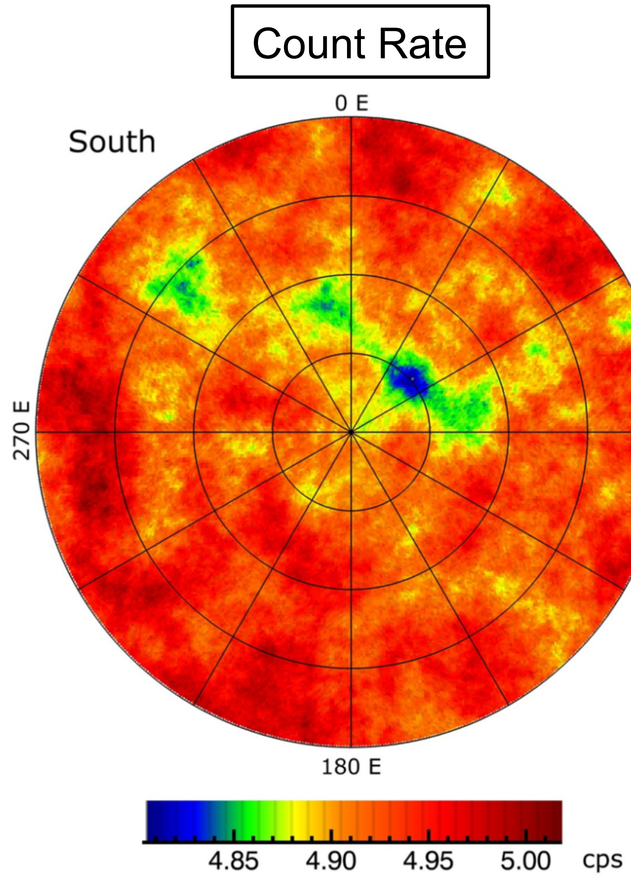
Early and late maps compared

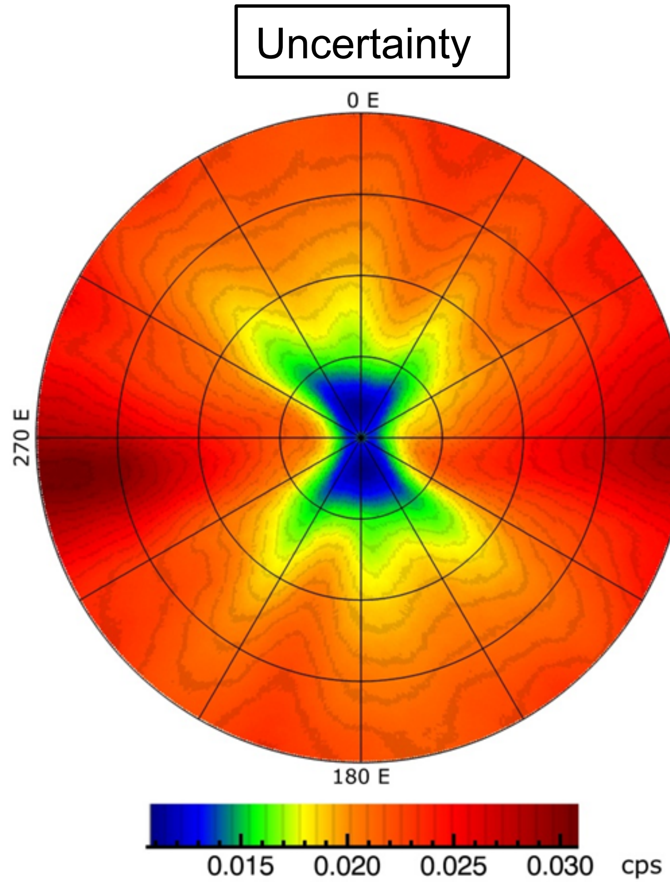
- First half and second half of data look very different when not processed properly. Dynamic range is 3.8 to 6.2 cps.
- Our biggest suppression is 0.2 cps, so at this scale we see only noise.



Smoothed data

- Suppressions are 0.1 to 0.2 cps; uncertainties are 0.01 to 0.02 cps





Summary

- LEND maps with proper smoothing show statistically valid suppressions.
- LEND spatial resolution is just as advertised
- LEND uncertainties are properly estimated.
  - They account for all scatter in the data.

Neutron Suppression Regions at the Lunar Poles

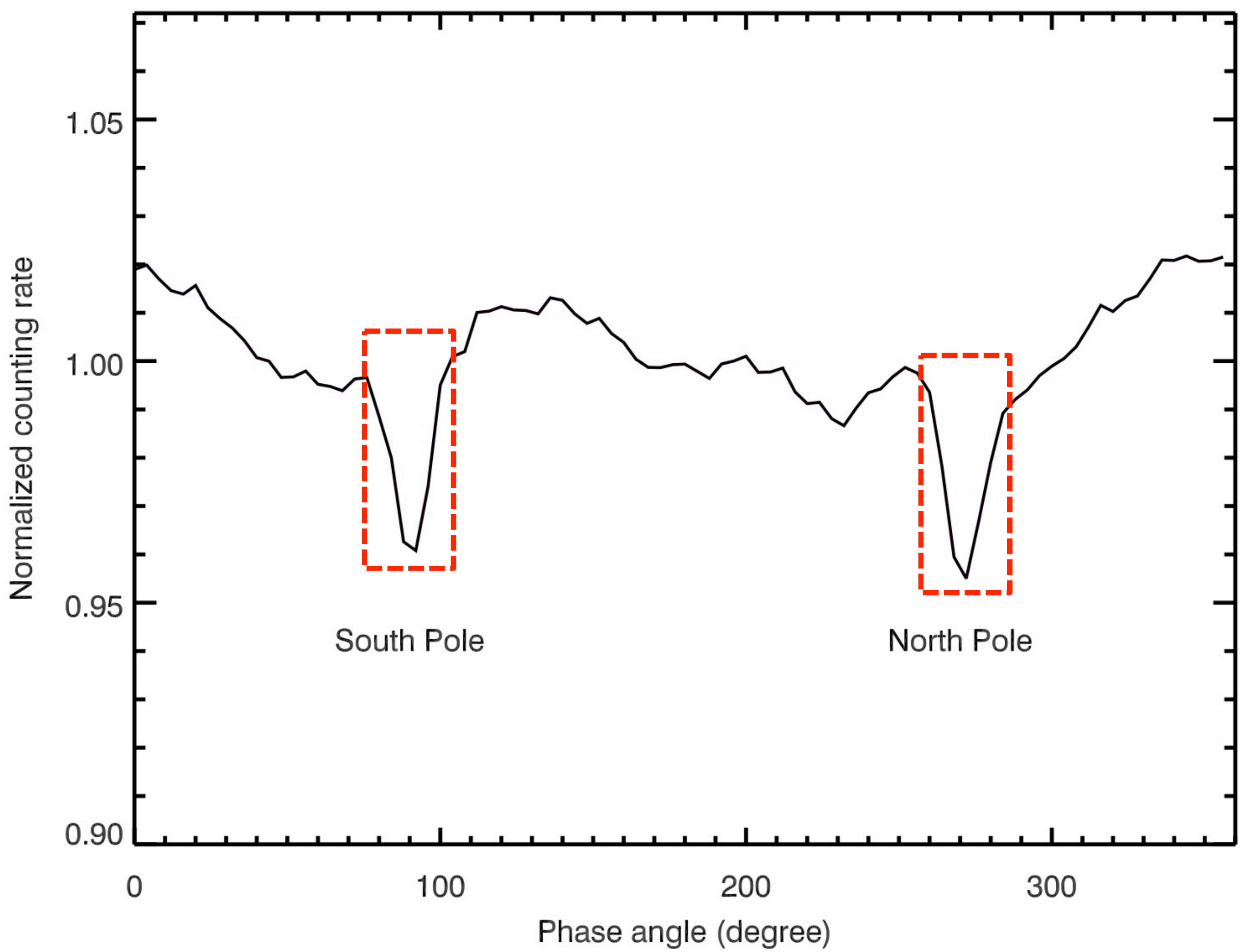
Part 2: Science results

Igor Mitrofanov, **Maxim Litvak**

Lunar Science Forum

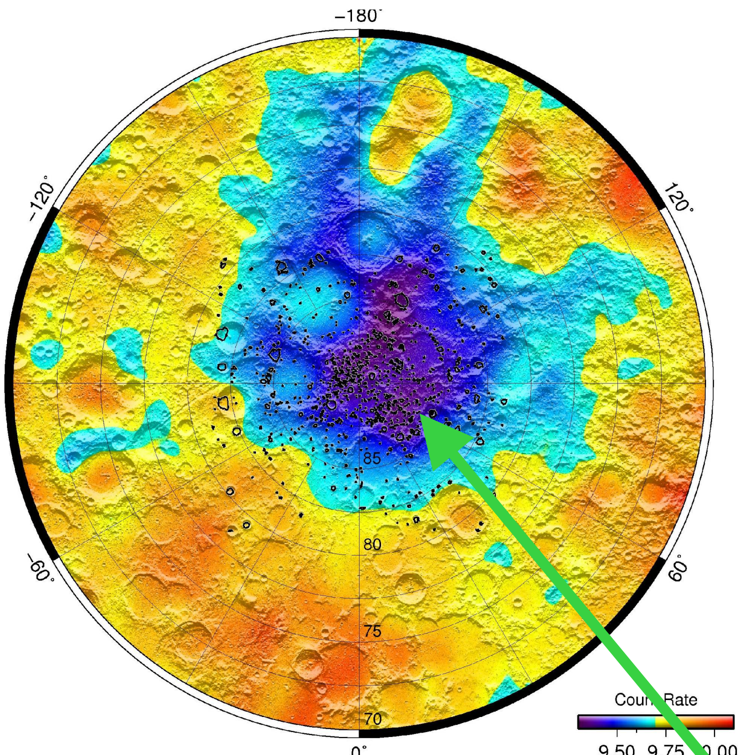
July 18, 2012

Global maps of epithermal neutron flux show the existence of extended suppression (~5%) of epithermal neutron flux at the polar regions of Moon poleward 70N/70S.

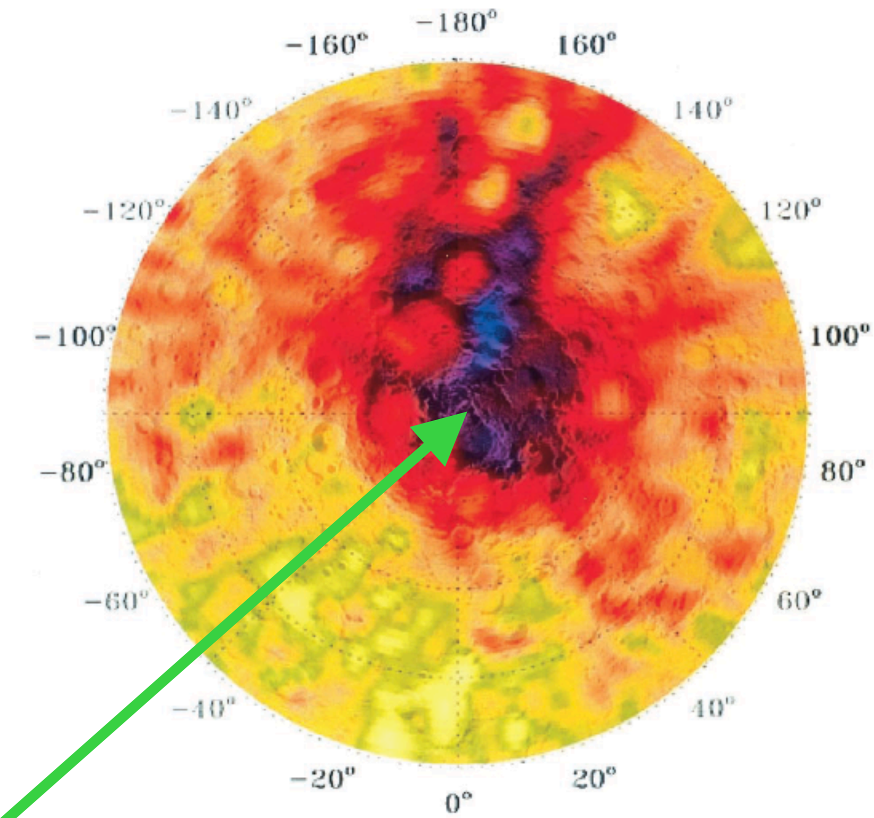


Neutron flux from North polar region with resolution ~50km

LEND (Litvak et al.,2012)



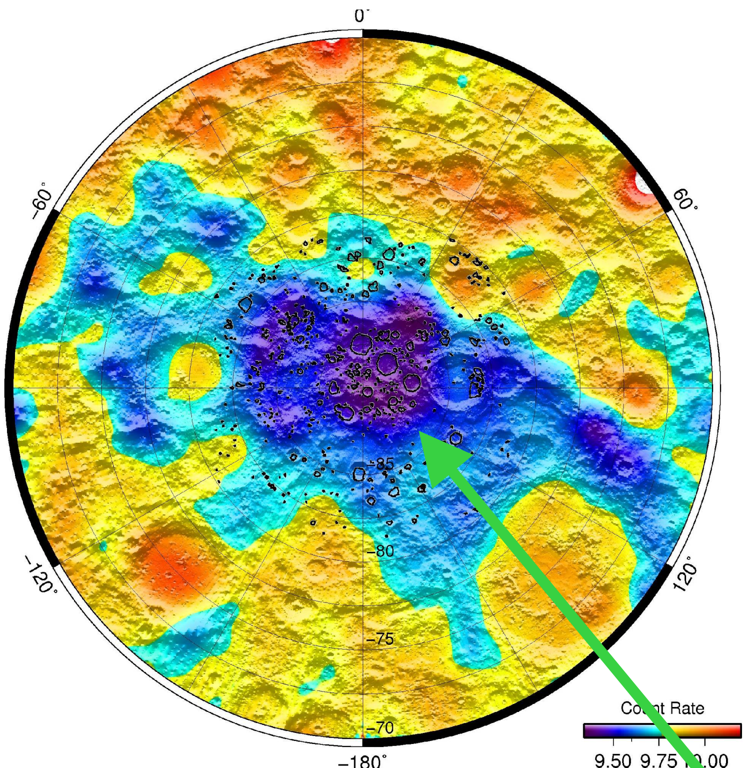
LPNS (Feldman et al., 2001)



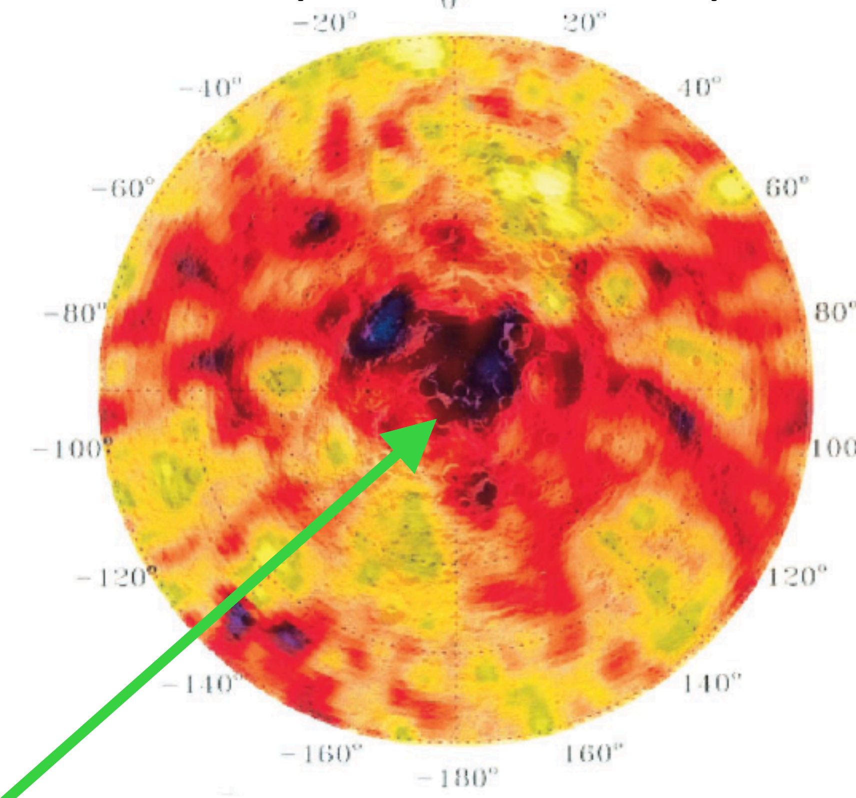
H-rich areas

Neutron flux from South polar region with resolution ~50 km

LEND (Litvak et al., 2012)



LPNS (Feldman et al., 2001)



H-rich areas

Hydrogen at Moon Poles:

There are two possible sources of hydrogen found on the moon:

H_2O from impacts of volatile-rich comets or meteorites.

H created in the subsurface due to interaction with protons of the solar wind or solar particle events (SPEs). H-volatiles can be accumulated in the cold traps in the quantities comparable with the predictions derived from neutron spectroscopy data.

- Water on the Moon has also been recently detected by IR imaging spectrometers (Clark et al., 2006; Sunshine et al., 2006; Pieters et al., 2006); the IR data have shown that the content of water (or OH group) is gradually increasing toward both poles.

- Recently, the joint efforts of NASA`s LRO and LCROSS missions have provided the most direct evidence to date that regolith of the southern polar crater Cabeus contains significant amounts of water and other volatiles (Colaprete et al., 2010; Gladstone et al., 2010).

- The direct estimation of mass fraction of water in the Cabeus regolith gave about 5.6±2.9 weight % by instruments onboard LCROSS (Colaprete et al., 2010).

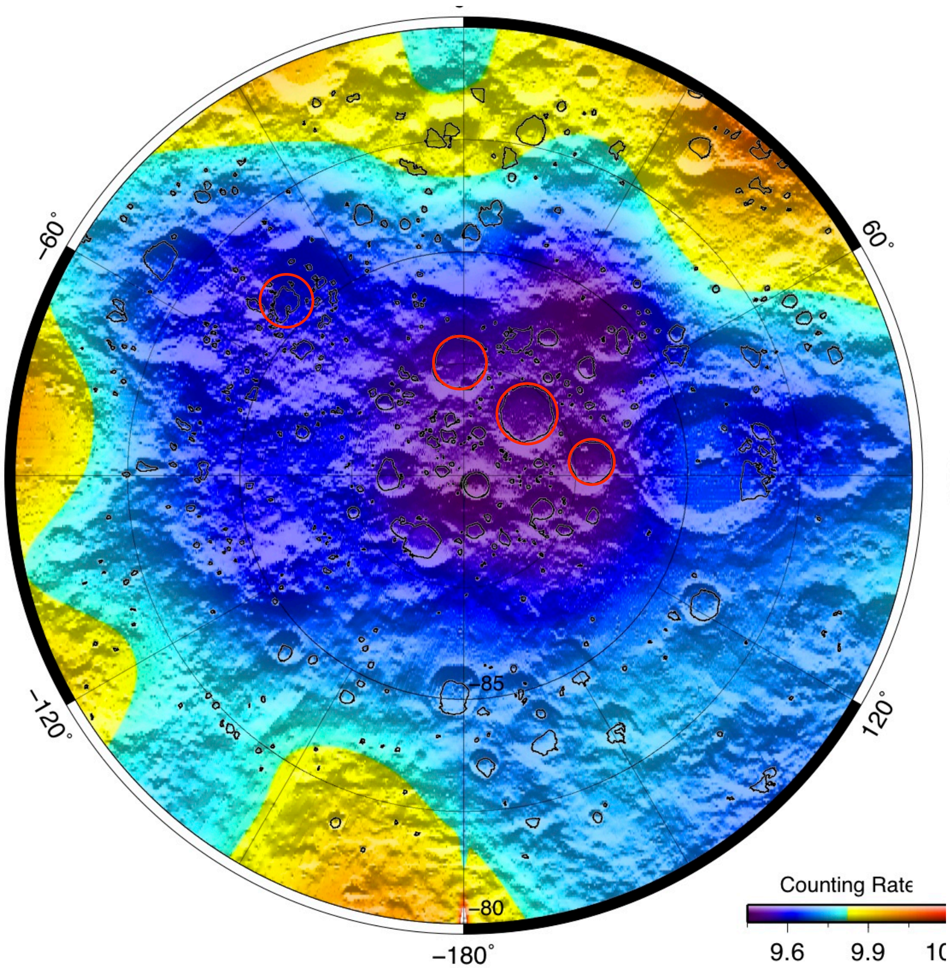
- Therefore, one may conclude that enhanced content of hydrogen and/or water at the lunar poles is experimentally proven and et least one local spot enriched with water is detected in the crater Cabeus.

- Several questions arise: Where are another spots of water-rich permafrost at the lunar poles? Are they coincide with PSRs? How much do water-rich spots contribute to the bulk quantity of polar water on the Moon?

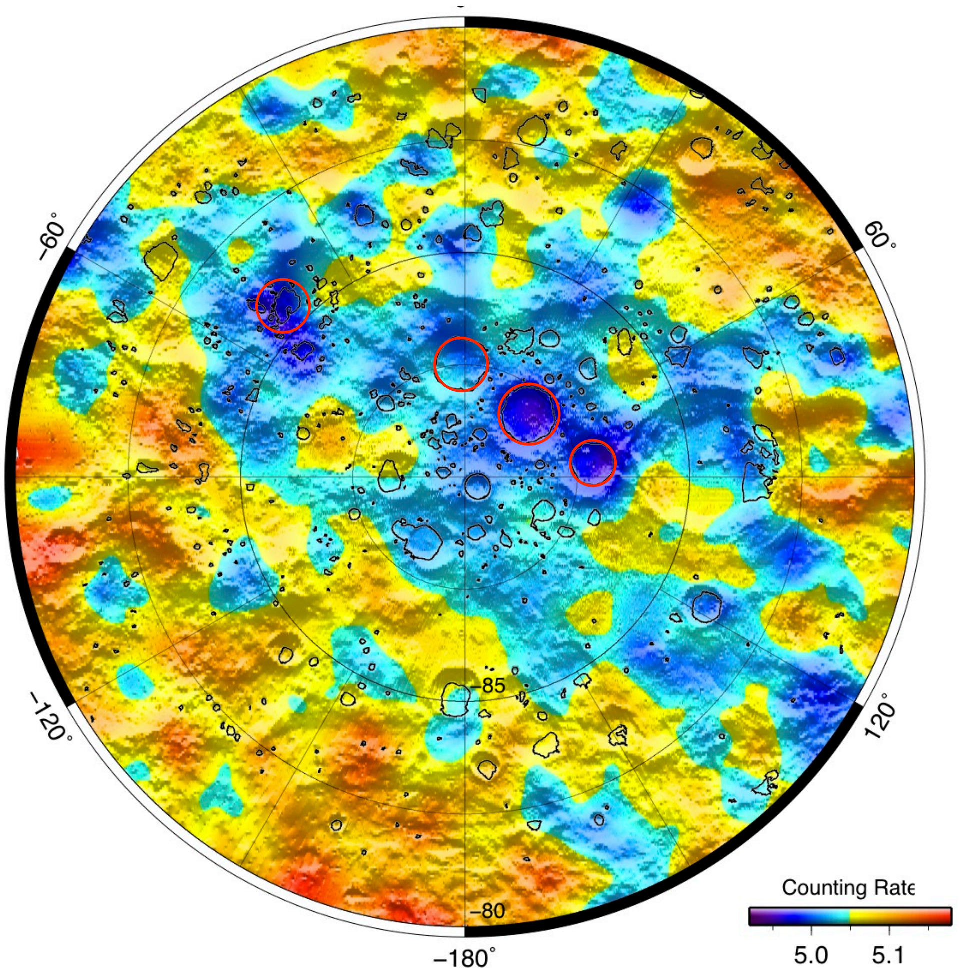
The data from neutron telescope LEND (selected for NASA`s LRO mission) could be analyzed to provide answers to these questions. LEND collimated neutrons detectors are able to measure epithermal neutron emission with high spatial resolution of about 5 km (HWHM) at altitude of 50 km. It is comparable with possible local spots of H enhancement.

Polar maps of epithermal neutron flux with different spatial resolution

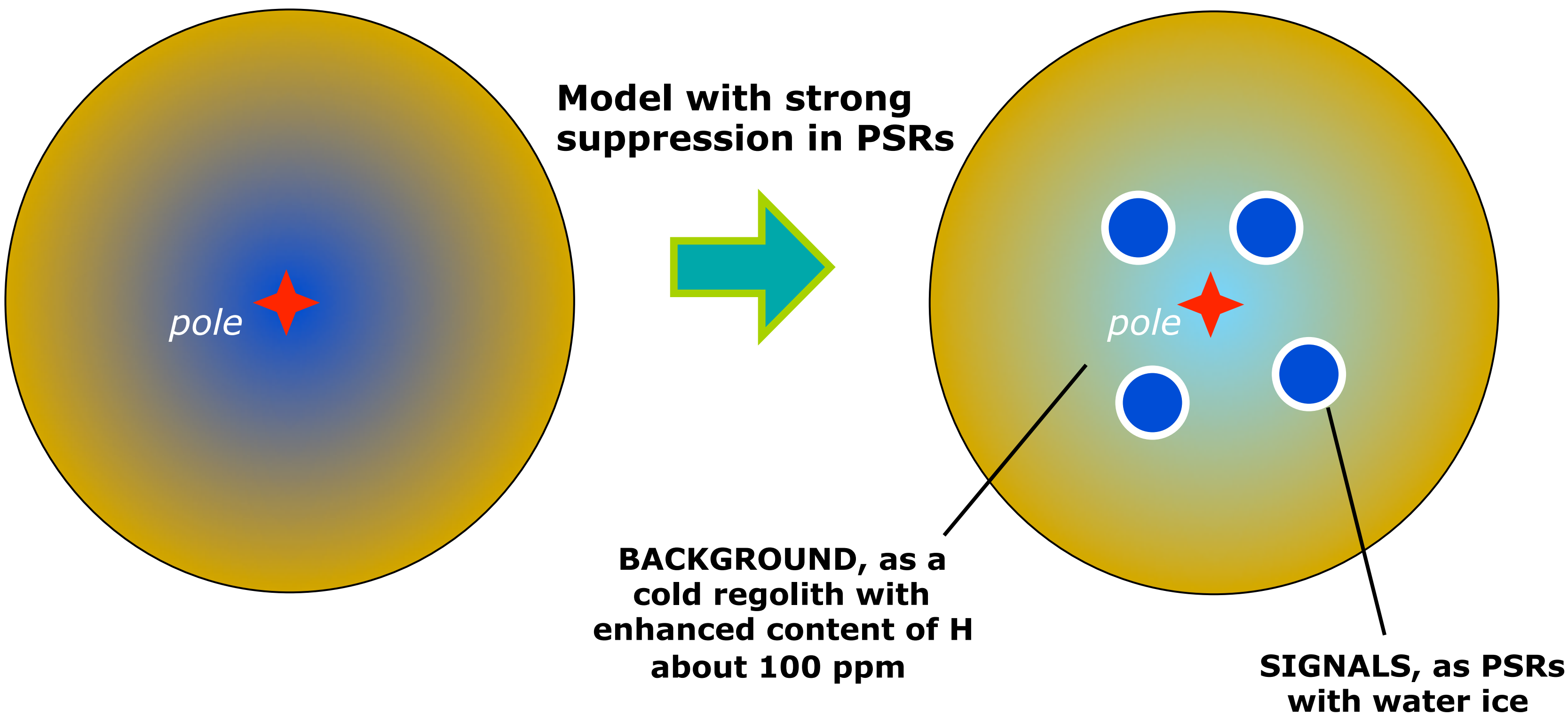
Omni-directions sensor
FWHM~75 km

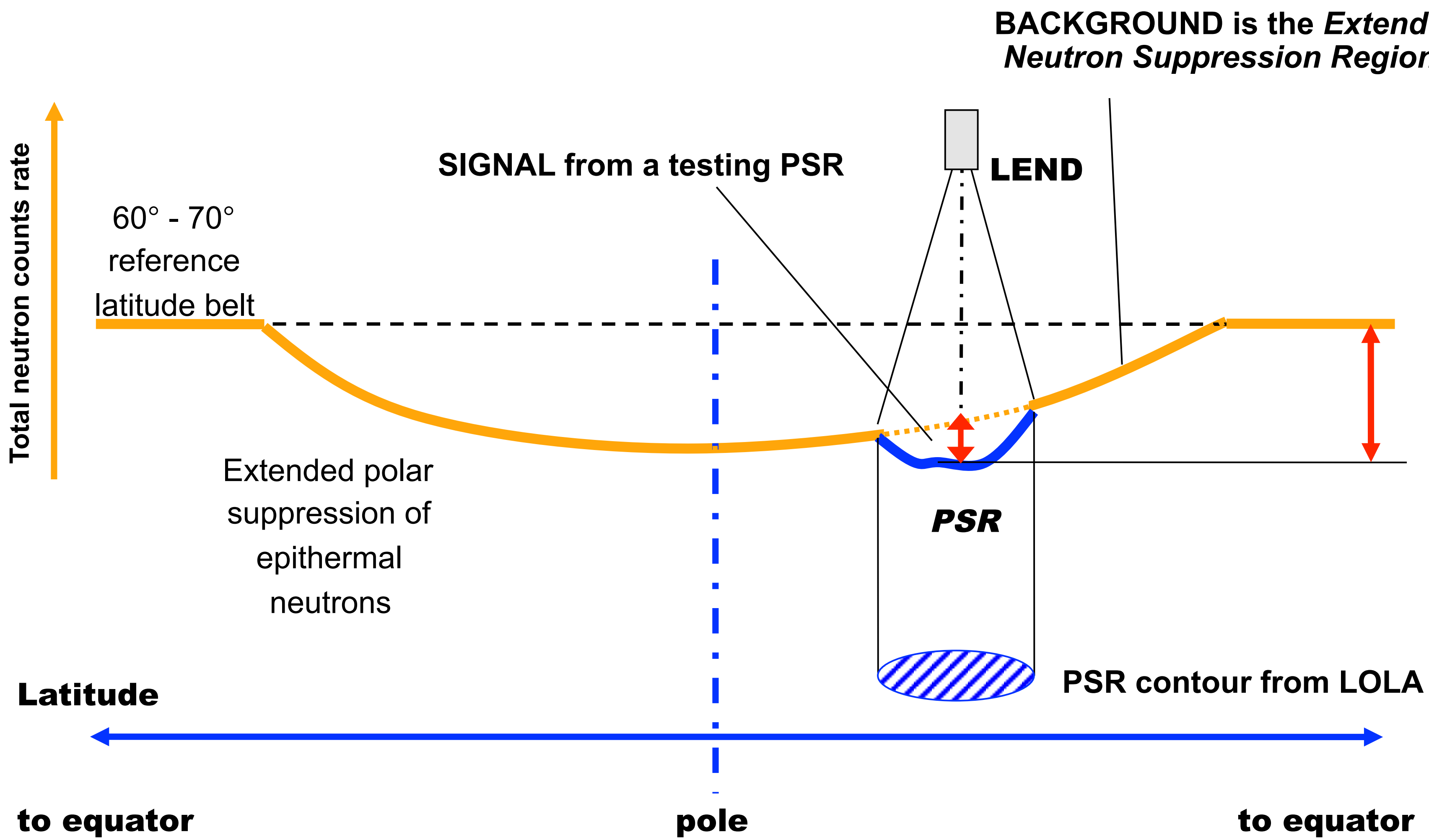


Collimated sensors
FWHM~10 km



TASK I: To test the hypothesis that water ice deposits exist in cold traps of Permanently Shadowed Regions (PSRs)

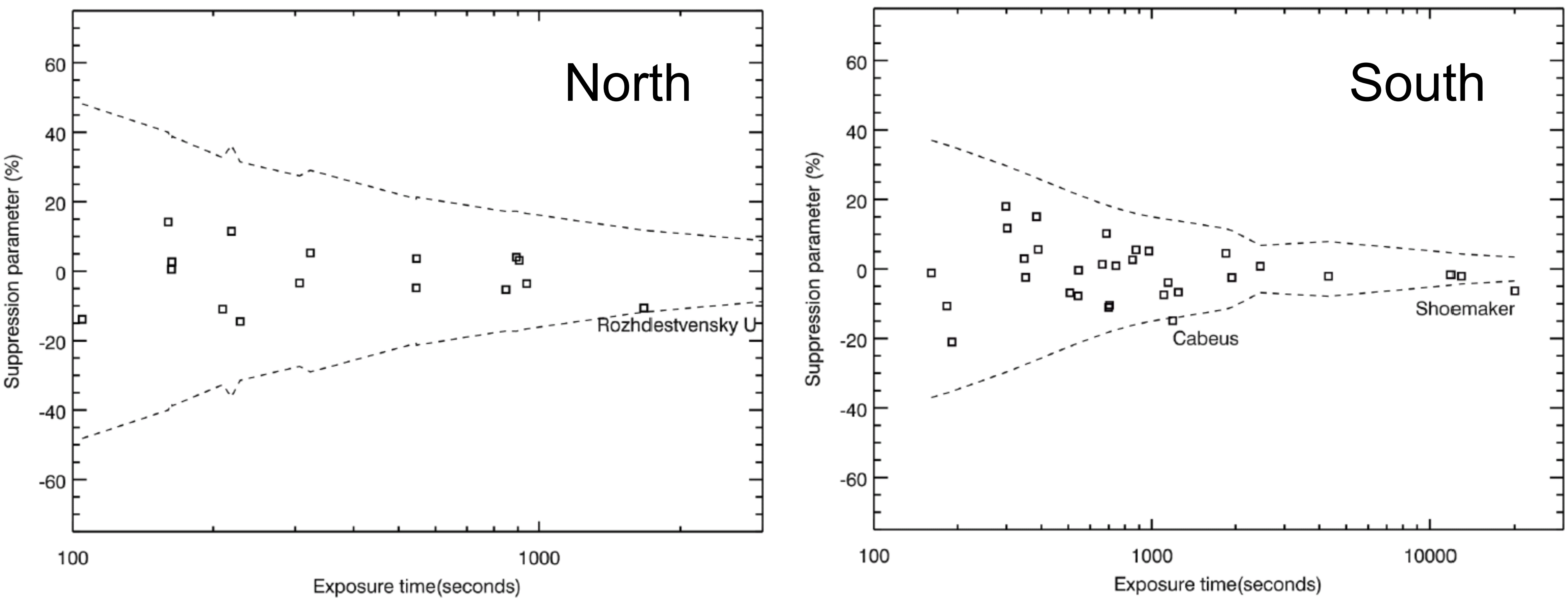



BACKGROUND is the *Extended Neutron Suppression Region*
SIGNAL from a testing PSR
LEND
Total neutron counts rate
60° - 70° reference latitude belt
Extended polar suppression of epithermal neutrons
PSR
PSR contour from LOLA
Latitude
to equator
pole
to equator

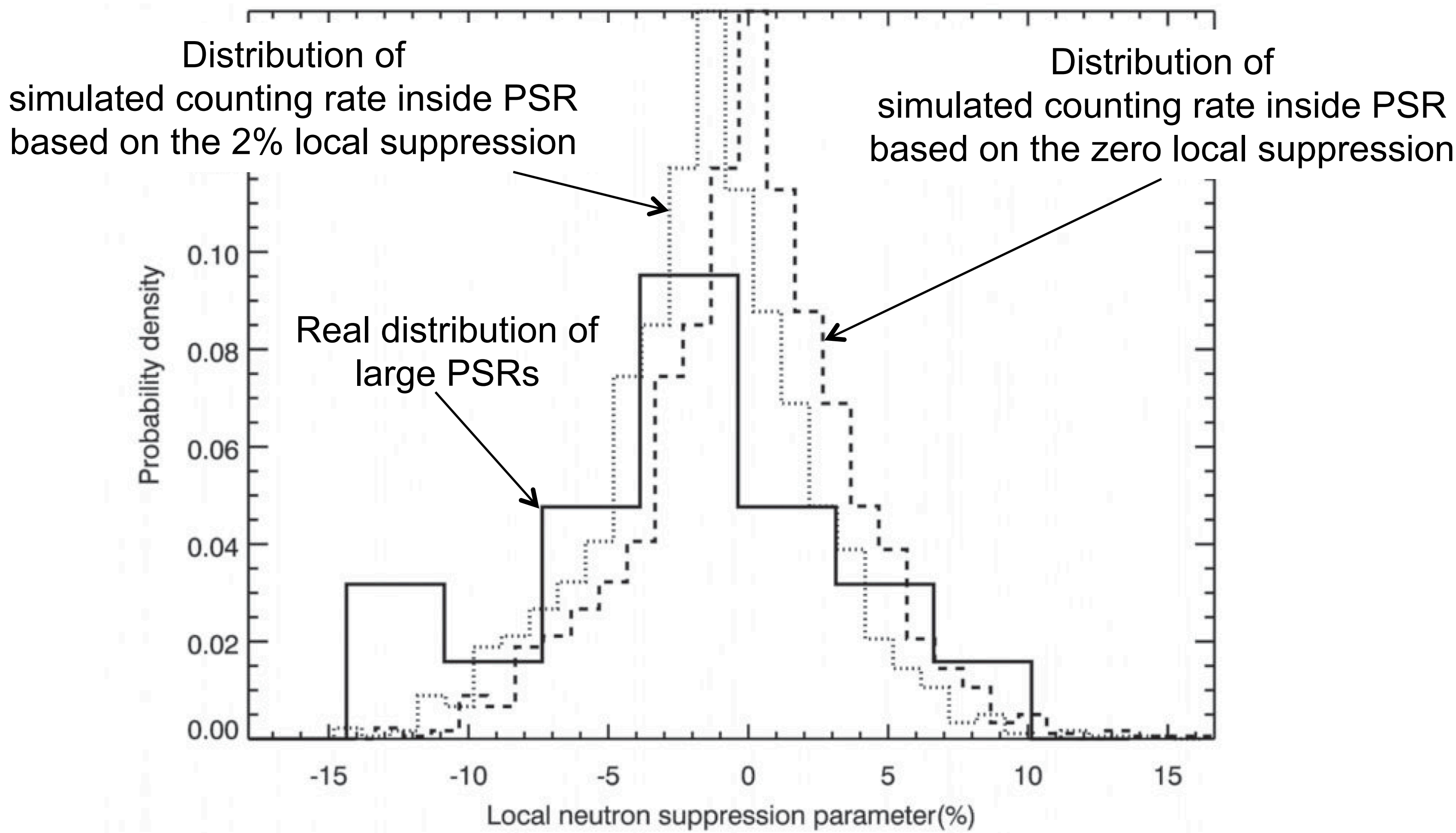
RESULTS of testing SIGNAL (local suppressions) at PSRs: list of largest cases

Name of Crater contained PSR or nearest crater	PSR area, km^2	Exposure, sec	Min Lon, deg	Max Lon, deg	Min Lat, deg	Max Lat, deg	Local suppression #1	Local suppression #2
Shoemaker	**1079.99**	**20065.88**	**27.0**	**63.5**	**-88.6**	**-87.4**	**-5.5% ± 1.2%**	**-6.3% ± 1.1%**
Haworth	1019.21	12883.67	-17.3	12.5	-88.1	-86.9	-1.4% ± 1.5%	-2.1% ± 1.4%
Faustini	665.25	4315.42	74.1	94.2	-87.6	-86.7	-2.0% ± 2.6%	-2.1% ± 2.6%
Sverdrup	550.53	11832.28	-161.0	-123.0	-88.6	-87.8	-1.3% ± 1.6%	-1.7% ± 1.6%
Amundsen	405.20	686.13	87.0	95.3	-83.8	-83.0	9.3% ± 6.6%	10.2% ± 6.6%
Rozhdestvenskiy U	**390.68**	**1676.84**	**148.3**	**158.1**	**84.2**	**85.0**	**-11.3% ± 3.9%**	**-10.6% ± 3.9%**
Cabeus B	382.29	976.05	-57.4	-51.9	-82.0	-81.3	4.4% ± 5.3%	5.2% ± 5.3%
Lovelace	339.32	906.26	-112.7	-107.4	81.1	81.8	2.5% ± 5.7%	3.1% ± 5.6%
Idel'son L	325.90	1103.30	115.2	121.9	-84.2	-83.5	-7.7% ± 4.9%	-7.4% ± 4.8%
Sylvester	320.69	545.91	-84.4	-78.6	81.7	82.2	2.4% ± 7.1%	3.6% ± 7.1%
Malapert C (PSR is out of the crater)	306.92	851.43	8.5	13.4	-82.5	-81.7	2.8% ± 5.7%	2.7% ± 5.7%
Cabeus	**283.09**	**1188.81**	**-50.4**	**-42.6**	**-84.7**	**-84.1**	**-14.4% ± 4.7%**	**-14.9% ± 4.7%**
Lenard	281.42	940.32	-113.1	-104.4	84.4	85.1	-3.0% ± 5.5%	-3.6% ± 5.5%
de Gerlache	242.47	1940.03	-101.4	-78.0	-88.6	-88.0	-2.0% ± 3.7%	-2.5% ± 3.7%
Rozhdestvenskiy K	241.18	545.07	-148.2	-143.5	81.3	82.1	-6.1% ± 6.9%	-4.8% ± 6.9%
Nansen F	225.26	893.82	59.0	66.3	83.9	84.6	3.8% ± 5.8%	4.0% ± 5.7%
Haworth (PSR at flat terrain out of the crater)	222.92	1245.08	16.3	26.8	-87.1	-86.3	-6.3% ± 4.6%	-6.7% ± 4.6%

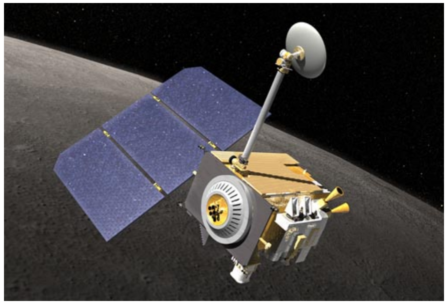
We selected only the large PSRs with areas greater than 100 km^2(comparable with the LEND footprint) There are 47 such PSRs in the South (30) and North (17) polar regions. Their area ranges from ~100 km^2 up to > 1000 km^2.



Local suppression parameter measured for each large northern and southern PSRs. It is presented as a function of exposure time accumulated during LEND observations for each PSR. The dashed lines correspond to the 3σ upper limits for excess (positive values) and suppression (negative values), respectively.



Distribution of counting rates measured inside large PSRs (surface area > 200 km^2) shown by solid black line. The distribution of simulated counting rates for these PSRs based on assumption of zero local suppression is shown by the dashed line. The distribution of simulated counting rates for these PSRs based on assumption of best fit local suppression is shown by the dotted line.



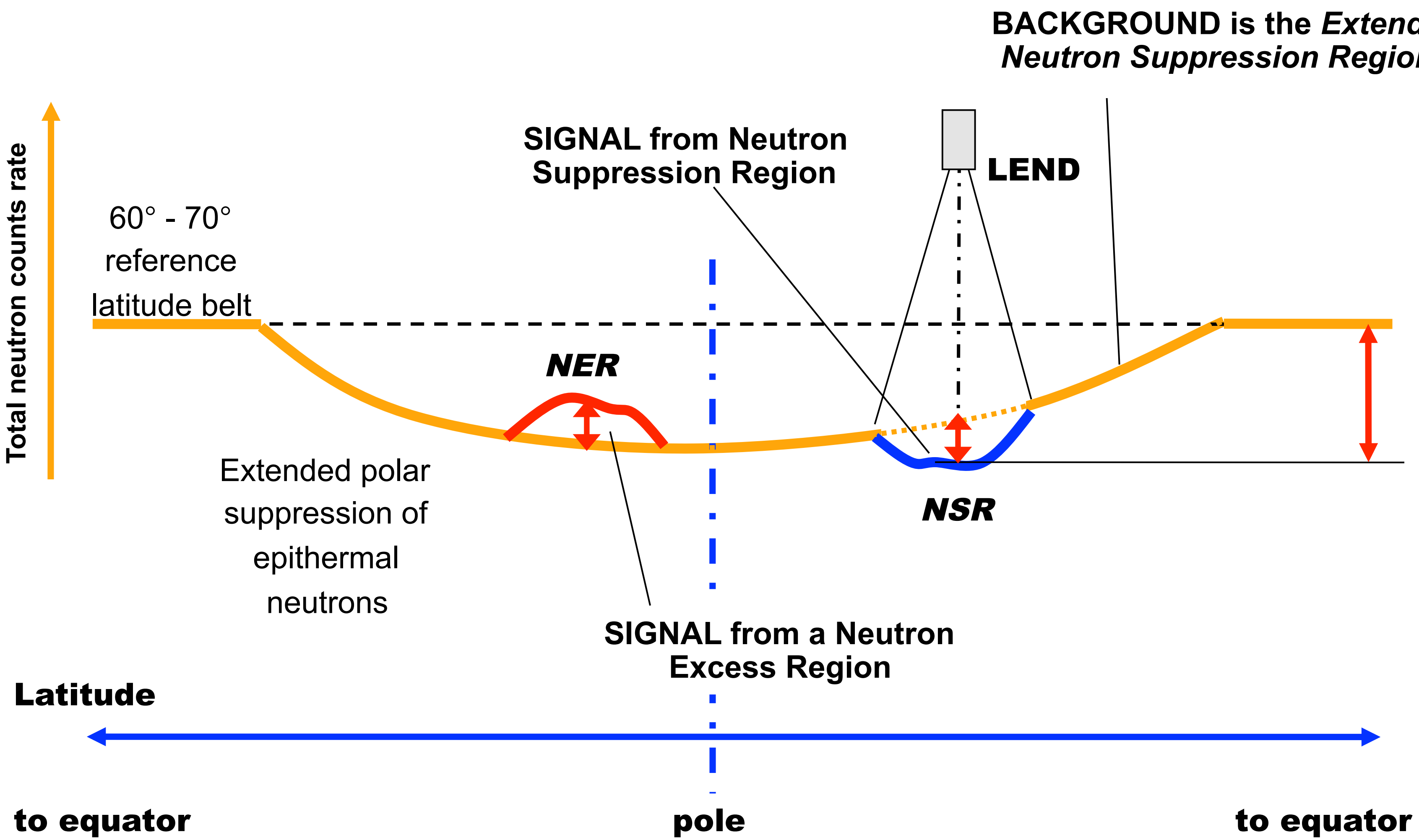
CONCLUSIONS for the TASK I

1. Some large PSRs have enhancement of Hydrogen: >250 ppm in Shoemaker, >500 ppm in Cabeus. Shoemaker and Cabeus are the best candidates for PSRs with water ice. For example, LEND estimations of water distribution in Cabeus (using double-layered model with poor H-material on the top) may be as high as 4% wt.

2. There is no statistically significant difference of neutron suppressions for most of largest PSRs in comparison with their local sunlit vicinity. But they tend to demonstrate less (by ~2% in average) neutron emission than surrounding areas.

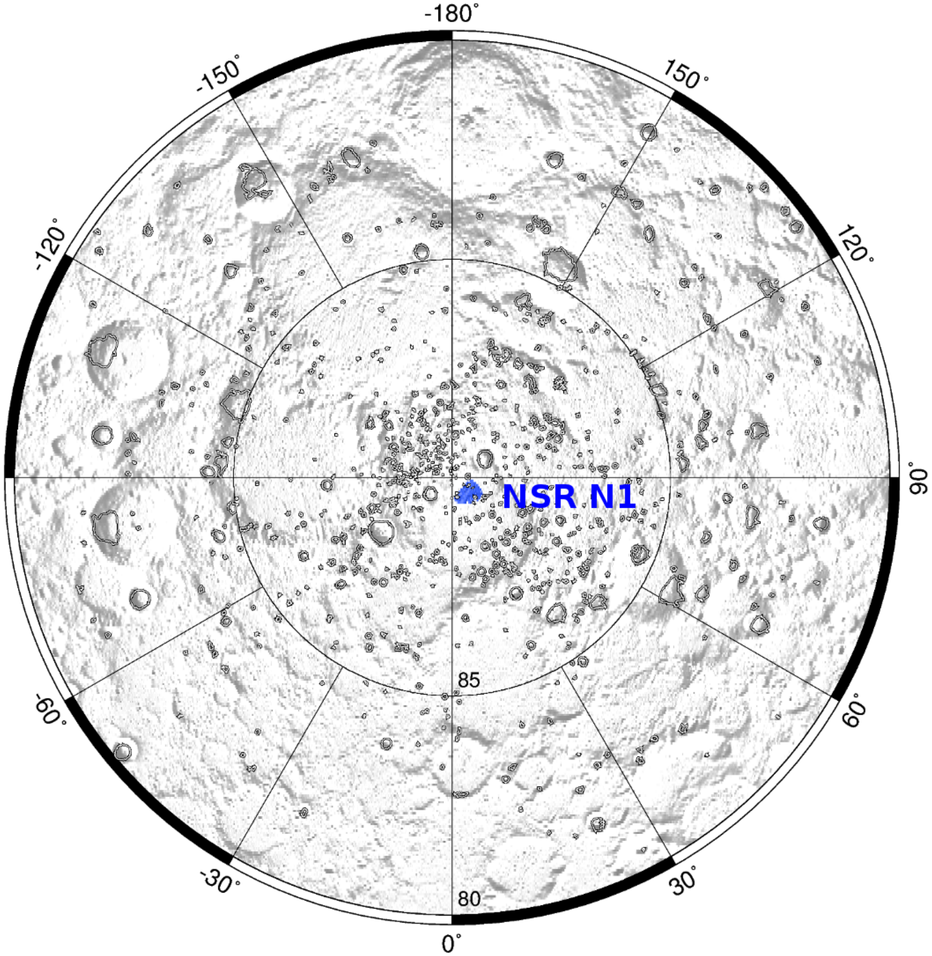
Based on these results, one may consider another TASK II:

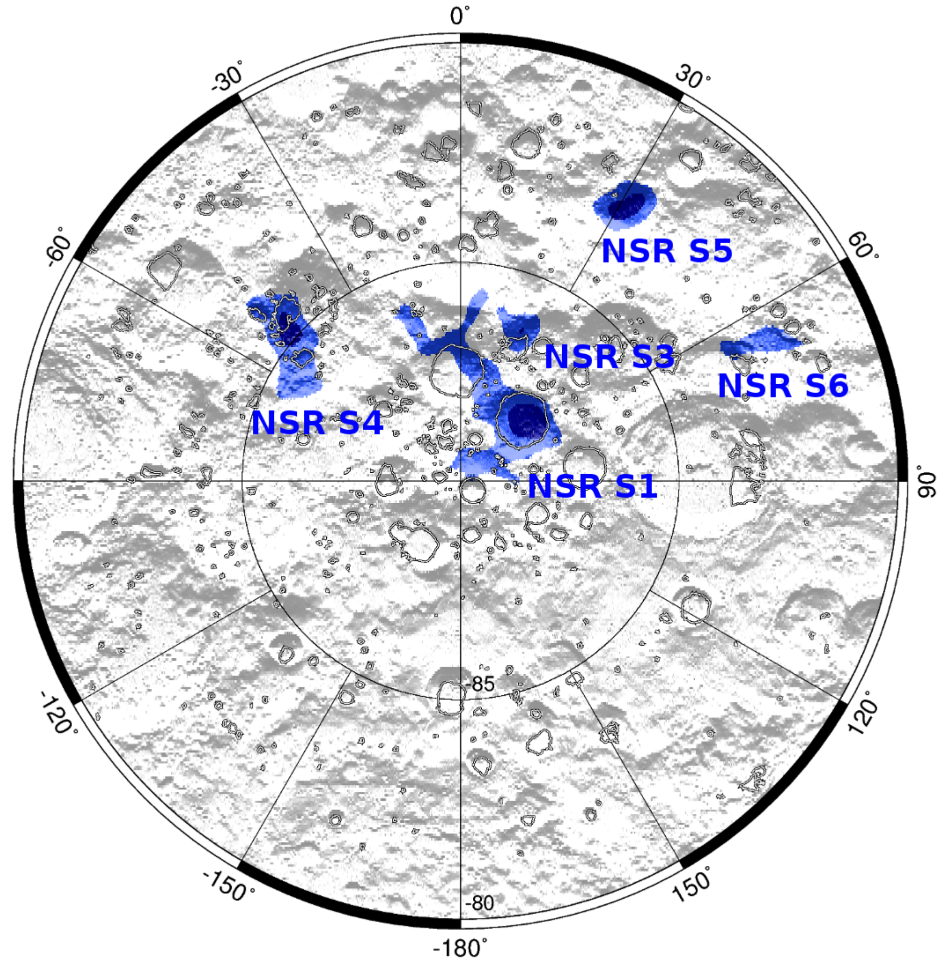
To search for local *NEUTRON SUPPRESSION REGIONS* (NSRs) based only on the LEND neutron mapping data without any a priory information.

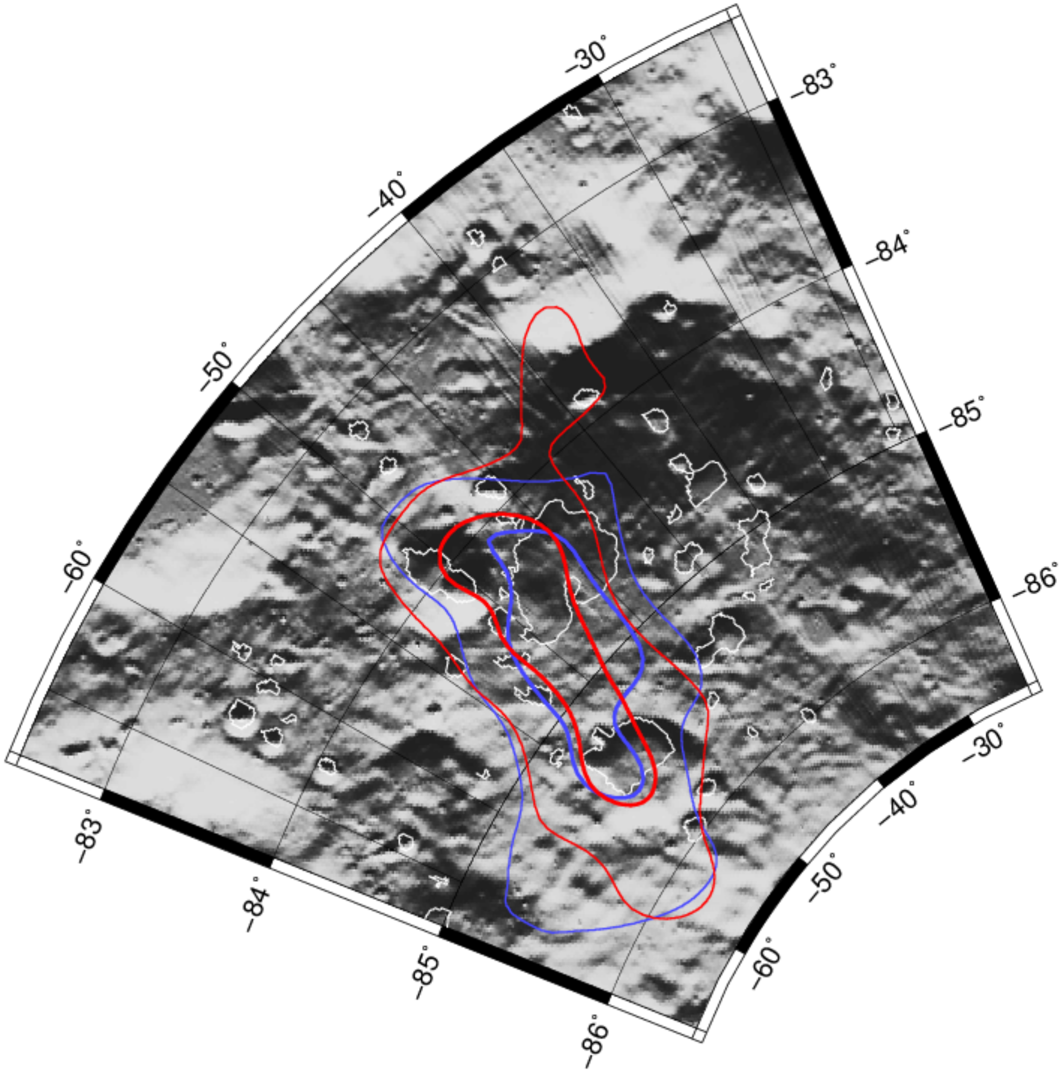


BACKGROUND is the *Extended Neutron Suppression Region*
SIGNAL from Neutron Suppression Region
LEND
Total neutron counts rate
60° - 70° reference latitude belt
NER
Extended polar suppression of epithermal neutrons
NSR
SIGNAL from a Neutron Excess Region
Latitude
to equator
pole
to equator

NSRs were found, as statistically significant decreases of epithermal neutron emission by 2.5% and 5.0% from the level of Extended Suppression







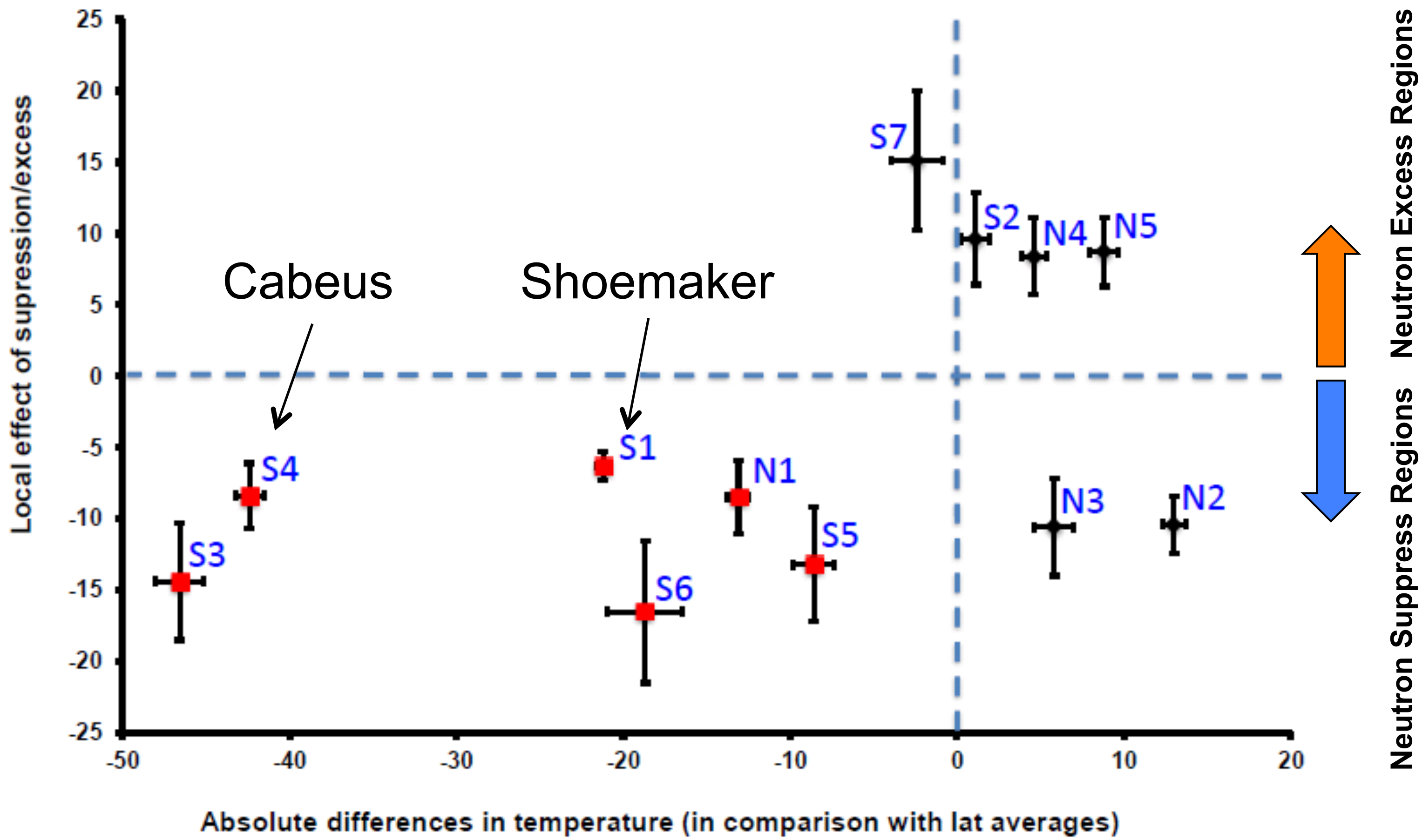
Example of contour of NSR in the vicinity of Cabeus area.

Blue line – first half of LRO mapping
Red line – Full LRO mapping

Neutron flux inside Neutron suppress/excess regions: possible correlation with surface properties (temperature and illumination)

Spot ID and crater name	Selection thresholds ±2.5%				Selection thresholds ±5.0%			
	Local effect of suppression or excess	Incident flux in 10^{-4} (with latitude average)	Illumination in % (with latitude average)	Average temperature in K (with latitude average)	Local effect of suppression or excess	Incident flux in 10^{-4} (with latitude average)	Illumination (with latitude average)	Average temperature in K (with latitude average)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
South								
NSR S1 Shoemaker	- 6.3 ± 1.0 %	145±3 (238±1)	11.1±0.2 (18.5±0.1)	72.7±0.4 (93.9±0.2)	- 12.2 ± 2.6 %	0±1 (179±2)	0.0±0.1 (14.4±0.1)	42.7±0.1 (83.7±0.3)
NER S2	+ 9.6 ± 3.2 %	215±8 (243±2)	22.7±0.4 (20.7±0.1)	97.8±0.8 (96.7±0.3)	+ 24.1 ± 7.0 %	134±13 (254±3)	15.1±0.9 (22.6±0.2)	82.2±1.7 (99.4±0.4)
NSR S3 Malapert	- 14.4 ± 4.1 %	86±8 (299±2)	6.0±0.4 (24.8±0.1)	60.3±1.4 (106.9±0.3)	-	-	-	-
NSR S4 Cabeus	- 8.4 ± 2.3%	99±5 (351±2)	6.9±0.3 (25.4±0.1)	69.7±0.8 (112.1±0.2)	- 14.9 ± 4.8 %	20±3 (325±3)	1.6±0.2 (24.2±0.1)	51.8±0.6 (109.1±0.3)
NSR S5	- 13.2 ± 4.0 %	364±16 (477±3)	24.5±0.5 (32.0±0.1)	119.4±1.2 (128.0±0.2)	-	-	-	-
NSR S6 Amundsen	- 16.5 ± 5.0 %	309±19 (469±3)	23.3±1.1 (31.2±0.1)	108.2±2.2 (126.9±0.2)	-	-	-	-
NER S7	+ 15.1 ± 4.9 %	445±18 (465±3)	29.1±0.7 (31.2±0.1)	125.4±1.5 (127.8±0.2)	-	-	-	-

Neutron Suppression/Excess Regions vs local temperature effect



Local effect of suppression/excess of neutron flux inside NSR/NER measured in % (vertical axis) vs absolute difference (horizontal axis) between a temperature inside NSR/NER and average temperature at given latitude (including given NSR/NER). The red points represent six spots, which have the property "*less local irradiation and lower temperature – fewer local neutrons*".

CONCLUSIONS for the TASK II

- Analysis of the LEND maps of epithermal neutron emission at the lunar poles shows that there is effect of significant variations of neutron emission at local spots called as *Neutron Suppression Regions* (NSRs) and *Neutron Excess Regions* (NERs).

- Some of NSRs are located in the vicinity of PSRs but do not coincide with them.

- All selected spots have been studied using independent data for solar irradiation from LOLA and for average surface temperature from Diviner. It was found that some neutron suppress regions have significantly different temperature and illumination in comparison with the average estimates at their latitudes.

- These suppress regions follow empirical law "*less local irradiation and lower temperature – fewer local neutrons*". We assume that the hydrogen content is the driving factor for this law.